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AEROSPACE
NUCLEAR
SAFETY

EXPERIMENTALLY DETERMINED DYNAMIC
SHEAR STRENGTH FOR SELECTED MATERIALS
(GUN TEST FACILITY)

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ABSTRACT

Cylindrical projectiles were impacted on selected materials to permit the calculation of the materials dynamic shear strengths. The materials were beryllium, Haynes-25 alloy, and titanium (6Al-4V) alloy which are the materials of construction for the SNAP-27 graphite lunar module fuel cask and fuel capsule assembly.

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SUMMARY

The materials of construction for the SNAP-27 graphite lunar module fuel cask and fuel capsule assembly were subjected to impacts of cylindrical projectiles. These tests were performed on beryllium, Haynes-25 alloy, and titanium (6Al-4V) alloy at various projectile velocities. The velocity was increased until perforation was accomplished. The tests were performed at the operational temperature expected during the launch pad phase of the Saturn V launch vehicle.

Beryllium exhibited brittle fracture at 900°F, while the other materials exhibited shear plug failure. Haynes-25 alloy at 1200°F had a calculated dynamic shear strength of 971,000 psi, and titanium alloy at 1100°F had a calculated dynamic shear strength of 266,000 psi.

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EXPERIMENTALLY DETERMINED DYNAMIC SHEAR STRENGTH FOR SELECTED MATERIALS (GUN TEST FACILITY)

Introduction

A test series was designed to establish the dynamic shear strengths of the materials used in the SNAP-27 secondary thermal shield (STS) and the fuel capsule assembly (FCA). The materials tested were beryllium, Haynes-25 alloy, and titanium (6Al-4V) alloy.

The dynamic shear strength, when determined for the test conditions used, is a quantity which is assumed to be constant for the given material and is used in the analytical model of Recht and Ipson in Reference 1. The term is present in the strain energy portion of the total energy expression of the deformation process. The value is obtained from an experimentally determined minimum perforation velocity which is described by Eq. (7) of Reference 1.

The dynamic shear strength is needed to permit calculation of the penetration resistance of the tested materials during the impact of debris generated during an explosive abort of the S-IVB stage of the Saturn V launch vehicle.

There are techniques for calculating the penetration of simple shapes by cylindrical projectiles, but the dynamic shear strengths of the materials of interest are not available and were required to complete the calculations for the penetration resistance of the SNAP-27 GLFC.

Test Objectives

Explosively propelled aluminum projectiles were impacted against plates of beryllium, Haynes-25 alloy, and titanium alloy to determine the dynamic shear strengths of these materials. The plates were impacted at velocities sufficient to cause perforation. The object of the test was to determine the dynamic shear strength property of the material so as to be able to use this property in the analytical model of Recht and Ipson.¹ All the tests were conducted with the target materials at approximately the operating temperature expected during the on-pad operational phase of the SNAP-27 graphite lunar module fuel cask (GLFC).

The plates were impacted at increasing velocities until perforation was accomplished; then the velocity was decreased in smaller increments until the projectile did not penetrate. This range of velocity for perforation or nonperforation was used to calculate the dynamic shear strength of each material for the test temperature.

Gun Test Facility

The gun test facility consists of a 0.50-caliber smooth bore rifle barrel attached to a modified 0.50-caliber gun receiver. The receiver was modified to allow electric pulse firing of the gun.

The aluminum cylindrical projectile was loaded in a standard 0.50-caliber cartridge case. The powder charge was varied to acquire the desired velocity of the projectile. The original test setup is shown in Figure 1. However, the rigid mounting was considered detrimental to the testing and was modified to allow the plate to be suspended from wires and backed up by three fingers to prevent swinging upon projectile impact (Figure 2). As noted in Figure 1 the plates were radiantly heated prior to projectile impact. The plates were heated to the nominal operating temperatures expected on the launch pad prior to actual launch vehicle lift off.

Test Results

The materials tested were beryllium, Haynes-25 alloy, and titanium (6Al-4V) alloy. These materials were 0.375 inch, 0.040 inch, and 0.125 inch thick, respectively. They were heated to approximately 900°, 1200°, and 1100°F, respectively, prior to projectile impact. Each plate was impacted at increasing velocity until either perforation was experienced or fracture occurred.

The two beryllium plates exhibited a brittle fracture of the entire plate (Figures 3 through 8), while the titanium and Haynes-25 exhibited a shear plug type of failure (Figures 9 through 12). The entire test series is summarized in Table I.

Titanium

The titanium plate was 0.125 inch thick and was mounted so that it could not swing away from the projectile but could rebound forward after projectile impact. The titanium used in the test was annealed plate and contained 6 percent aluminum and 4 percent vanadium. The projectile was a 0.50-inch diameter by 2.0-inch long aluminum rod. A minimum perforation velocity of 830 ft/sec at 1100°F was found. Using these results in the analytical model resulted in a calculated dynamic shear strength of 266,000 psi. The shear plug produced by the projectile was approximately 0.50 inch in diameter.

Haynes-25 Alloy

The Haynes-25 alloy plate was 0.040 inch thick and was mounted so that it could not swing away from the projectile but could rebound forward after projectile impact. The projectile was a 0.50-inch diameter by 1.0-inch long aluminum rod. A minimum perforation velocity of 750 ft/sec at 1200°F was found. A dynamic shear strength of 971,000 psi was calculated for the Haynes-25 alloy. The shear plug produced by the projectile was approximately the same diameter as the projectile.

Beryllium

The beryllium tests resulted in fracture of the entire plate and therefore were not applicable to the analysis since a shear plug must be formed. A 0.50-inch diameter by 2-inch long aluminum rod did not produce a hole in the 0.375-inch beryllium plate at 700 ft/sec. The first test of the beryllium plate resulted in the plate spalling and radially cracking from the impact point; the velocity was 670 ft/sec. The second test of the beryllium plate resulted in the plate spalling and shattering into six pie-shaped pieces. The velocity was 700 ft/sec. The target plate was an end slice of a 12-inch diameter cylinder of hot pressed block. The test temperature was 900°F.

Conclusions

These test demonstrated that beryllium at 900°F and under impact conditions exhibits a brittle fracture type failure; Haynes-25 alloy at 1200°F and titanium (6Al-4V) alloy at 1100°F under impact conditions exhibit a shear plug type failure. The two materials exhibiting shear plug type failure have calculated dynamic shear strengths of 971,000 and 266,000 psi, respectively.

TABLE I
Results of Test Series

Material	Impact Velocity (ft/sec)	Temperature at Impact (°F)	Penetration	Projectile (Aluminum 2024-T6) Size (in.)
Titanium ¹ (6Al-4V)	840	1100	Yes	0.5 dia. x 2
	450	1100	No	0.5 dia. x 2
	615	1100	No	0.5 dia. x 2
	913	1100	Yes	0.5 dia. x 2
	825	1100	No ⁶	0.5 dia. x 2
Haynes-25 Alloy ²	347	1200	No	0.5 dia. x 1
	406	1200	No	0.5 dia. x 1
	490	1200	No	0.5 dia. x 1
	760	1200	Yes	0.5 dia. x 1
	720	1200	No	0.5 dia. x 1
Beryllium ^{3,4}	670	920	Brittle fracture occurred and there- fore analyses cannot be performed. A shear plug must be formed.	0.5 dia. x 2
Beryllium ⁵	700	900		0.5 dia. x 2

1 - Titanium plates were 0.125-inch thick.

2 - Haynes-25 alloy plates were 0.40 inch thick.

3 - Beryllium plates were 0.375 inch thick.

4 - First beryllium plate was rigidly supported.

5 - Second beryllium plate had three-finger support, as did all titanium and Haynes-25 plates.

6 - Cracked dent.

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Figure 1. Original test setup

Figure 2. Final test setup

Figure 3. First beryllium plate (front)
after 670 fps impact

Figure 4. First beryllium plate (rear)
after 670 fps impact

Figure 5. First beryllium plate (front)
after 670 fps impact

Figure 6. First beryllium plate (rear)
after 670 fps impact

Figure 7. Second beryllium plate after
700 fps impact

Figure 8. Second beryllium plate
after 700 fps impact

Figure 9. Haynes-25 alloy (front)

Figure 10. Haynes-25 alloy (rear)

Figure 11. Titanium (6Al-4V) alloy (front)

Figure 12. Titanium (6Al-4V) alloy (rear)

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